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INVESTIGATION OF TECHNIQUES FOR CORRECTING ERTS DATA FOR SOLAR AND ATMOSPHERIC EFFECTS

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16. Abstract

This report summarizes the technical activity and accomplishments towards establishing a radiometric calibration technique that will permit the absolute reflectance characteristics of ground targets to be determined from ERTS spacecraft data. During this period the Radiant Power Measuring Instrument (RPMI) which permits the ERTS PI to obtain the needed solar and atmospheric parameters was completed. Characteristics and pictures of this instrument together with procedures being evaluated for its use are provided. Results of field measurements of atmospheric parameters and the use of these parameters to transform ERTS radiance into the desired target reflectance is reported.

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Preface

(a) OBJECTIVE

The objective of this experiment is to establish a radiometric calibration technique that will permit the absolute reflectance characteristics of ground targets to be determined from ERTS spacecraft data.

Intermediate Goals

The accomplishment of this objective is entailing the pursuit and accomplishment of intermediate goals that include:

- Development and evaluation of techniques to determine absolute reflectance of large natural and man-made targets from ground-based spot sampling.
- Development and evaluation of techniques to determine absolute target reflectance from ERTS data by the measurement and removal of the solar and atmospheric parameters derived from ground-based radiant power measurements.
- Inter-comparison of the capabilities of correcting the ERTS data for solar and atmospheric parameters and effects by candidate radiometric calibration techniques that include: (1) transference calibration, (2) ground-based radiant power measurements, (3) use of spacecraft data alone (no auxiliary inputs), and (4) radiation transfer models.
- Development and evaluation of computer software, techniques, and procedures for transforming the ERTS computer-compatible tapes (CCT) into a new set of tapes and images which have been corrected for solar and atmospheric effects.

(b) SCOPE OF WORK

To provide personnel and equipment necessary to develop Radiant Power Measuring Instruments (RPMI), deploy RPMIs to obtain solar and atmospheric parameters in concerts with aircraft and ERTS overflights, and to test and evaluate the procedures for using these parameters to transforming ERTS CCTs into a new set of tapes and images corrected for atmosphere. Using the performance achieved by the RPMI technique as a base-line compare effectiveness of alternative techniques to correct ERTS data for effects of atmosphere that degrade radiometric fidelity of ERTS data.

(c) CONCLUSION

Firm conclusions cannot be drawn until we receive ERTS data of test site which is concurrent with RPMI deployment. Most of this first reporting period was used to develop 5 RPMIs and to start the field measurements with these instruments. Based on RPMI measurements however, we have established that solar and atmospheric parameters are degrading the radiometric fidelity of ERTS data by large amounts. The RPMI is responsive to this problem and will permit ERTS PIs to make the measurements needed to transform their ERTS data into absolute target reflectance signatures.

Beam transmittance τ was determined to vary more than 6.0% within a single band on a clear day. Path radiance L_{ATM} was found to account for 50% or more of the radiance signal received by ERTS when viewing some targets. Global irradiance, H, if not corrected for, causes the radiance received by the spacecraft to vary by several hundred percent.

Correcting ERTS data for solar and atmospheric parameters will significantly enhance its usefulness for all application. Standardization of the measurements, recording, and reporting of solar and atmospheric parameters will be essential if the observations and reports of large numbers of PIs are to be correlated and compared by NASA and other PIs in a meaningful way.

(d) SUMMARY OF RECOMMENDATION

This experiment is evaluating the capability of candidate techniques for determining and removing solar and atmospheric parameters from ERTS data to obtain absolute target reflectance signatures. It is recommended that this program be expanded some to start addressing the basic question, "what is the value of these atmospheric corrections?" The recommended program would determine ERTS data applications that benefit most from atmospheric corrections, establish a dollar estimate for these benefits, determine cost of providing corrections by alternative techniques, and establish the benefit-to-cost ratio or value for applications and calibration techniques.

INVESTIGATION OF TECHNIQUES FOR CORRECTING ERTS DATA FOR SOLAR AND ATMOSPHERIC EFFECTS

1. INTRODUCTION

This report summarizes the results of the first 6 months activity to establish a radiometric calibration technique that will permit the absolute reflectance characteristics of ground targets to be determined from ERTS spacecraft data.

Program Scope

In response to ERTS PIs need for absolute target reflectance signatures, this experiment is to evaluate the capabilities of a wide range of candidate techniques for determining and removing solar and atmospheric parameters and effects from ERTS data. Techniques to be evaluated include transferring known ground reflectance to spacecraft measurements, the use of the ground-based RPMIs to measure directly the needed solar and atmospheric parameters, radiation transfer models, and the use of spacecraft data without auxiliary inputs. ERTS MSS computer compatible tapes (CCTs) will be transformed into reflectance, by use of factors derived from these calibration techniques, and the computed reflectance compared with known values from ground truth. Reflectances of the truth sites, located near Ann Arbor, Michigan, are to be determined from ground-based spot sampling with the hand-held RPMI. Results of this effort are to include a knowledge of the accuracy achievable by various calibration techniques, specifications for RPMIs optimized for ERTS that permit direct measurement of atmospheric parameters and truth site reflectance, and computer techniques for correcting ERTS CCTs for atmospheric effects.

Brief Summary of Accomplishment

In this first reporting period accomplishments included: completion of design and development of five RPMIs for ERTS ground truth, developed preliminary descriptive material for ground truth team describing how to perform field measurements of solar and atmospheric parameters with RPMI, initiated daily (local) field data gathering with RPMIs to determine instrument capability and correlation of instrument measurements with meterological data. In the ERTS data handling area we have developed computer software and techniques to screen ERTS CCT on moving window

TV display, transform data viewed on display into gray-scaled computer printout to facilitate locating truth sites. We have also transformed our first ERTS data into reflectance units using measured solar and atmospheric parameters.

2. ACCOMPLISHMENTS

As noted in the introduction the primary activities and accomplishments during this period have focused on the development of the RPMIs specifically for ERTS ground truth and the development and evaluation of the procedures for using these instruments and its measurements to transform ERTS data to reflectance. Specific goals achieved during this first 6 month period listed in the approximate order of completion are summarized below.

2.1 Analytical Studies - Reports and documents defining candidate radiometric calibration techniques for determining and removing solar and atmospheric parameters and associated variations in ERTS data have been compiled, reviewed, and evaluated.

2.2 Five (5) Radiant Power Measuring Instruments have been built and tested. The completion of the development of these instruments was reported in December 1972 as a significant accomplishment. A new technology report also was prepared and submitted describing RPMI as required in January 1973. A copy of this report is the Attachment-1.

The RPMI also described in Attachment-2, Section 4 provides an ERTS PI with the full capability needed to obtain radiometric measurements required to determine the solar and atmospheric parameters that degrade the radiometric fidelity of ERTS data. With these parameters, ERTS radiance measurements can be transformed into absolute target reflectance signatures.

2.3 Correlation of Instrument Measurements with Meteorological Data, Evaluation of Test Site Calibration Techniques and Field Data Gathering.

Procedures used and results of rooftop and field data gathering with RPMI is discussed in Attachment-2, Section 4.1.

Correlation of Instrument Measurements with Meteorological Data - Immediately upon completion of the RPMIs, rooftop and field data gathering started. These activities have included performing daily (hourly) measurements of solar and atmospheric parameters with RPMI and the evaluation of the correlation of these measurements with local meteorological data (i.e., visibility). This task which will continue under the field data gathering and field support task has not shown any significant correlation between the measured solar and atmospheric parameters and visibility.

Evaluation of Test Site Calibration Technique - The test site for this experiment has a rectangular shape, with 4 sides approximately 100 n.mi each. The center of this area is Ann Arbor, Michigan. Targets, both natural and man made (lakes, vegetation, airport runways, etc.) within this area have been selected for truth sites. RPMIs have been deployed by Bendix personnel and Mr. M.L. Bryan, ERTS U201 PI at the Environmental Institute of Michigan to perform spot-reflectance measurements of these targets. Mr. Bryan has also used a RPMI to measure the reflectance of many types of ice and snow in upper Michigan. Mr. Roland Hulstrom of the Martin Marietta Corporation, Denver, Colorado is also deploying an RPMI to measure target reflectance as well as solar and atmospheric parameters.

The use of RPMI to obtain absolute reflectance of truth sites will continue and is a basic part of field data gathering and support task. The development of an accurate and repeatable technique for determining absolute reflectance of large area targets, based on spot sampling techniques, will minimize the need for aircraft support by ERTS PIs.

Early Validation of Technique and Field Data Gathering - The NASA C-130 aircraft is planning a mission to support this investigation on March 28, 1973 concurrent with an ERTS overflight. Low and high altitude flights are planned. I have informed all ERTS PIs within this area of this aircraft-ERTS mission to maximize the utility of this aircraft while here.

Spot reflectance measurements of truth sites will be made with RPMIs, the aircraft data will expand these reflectance measurements over large areas. The reflectance derived from aircraft and RPMI spot sampling will be compared to reflectance derived from ERTS data using RPMI determined solar and atmospheric parameters. The accuracy and capability of these techniques will be determined and reported.

Field data gathering to evaluate RPMIs and measurement techniques are being conducted at the present time by Bendix personnel, R. L. Hulstrom of Martin Marietta in Denver, Colorado, and M. Leonard Bryan of The University of Michigan. Results of Bendix measurements are summarized in Attachment-2, Sections 4.1 and 5. Mr. R. L. Hulstrom found the RPMI derived measurement of solar constant H_o to be within 5 to 7% of values determined in Ann Arbor, Michigan. Hulstrom's measures were performed in Denver at 9000 ft altitude at a temperature of -20°F. We believe that the error is due to the path radiance in the relatively large 6° circular field of view. Experiments are underway to characterize the error as a function of field of view size. Mr. Hulstrom is to repeat his RPMI measurements at 12,000 ft in Denver. Mr. Hulstrom and Mr. Bryan are finding that the RPMI is very responsive to PI needs for a rugged field instrument that provides a fast measurement of the ERTS solar and atmospheric parameter.

2.4 First-Look Technique Evaluation

Since the completion of the RPMIs, local weather conditions have prevented RPMI atmospheric measurements on the same day as an ERTS overpass. Our next opportunity is March 9 and 10 in this area. We have however processed an ERTS tape from the 28 September 1972 overpass of our site and used RPMI measurements from 12 February 1973 to obtain a first-look at the overall measurement-processing procedure. This has permitted us to confirm that our data processing technique is correct. The results of this first-look at transforming ERTS data to reflectance is summarized in Attachment-2, Section 5.

Data processing steps taken and confirmed as correct include:

1. Screening ERTS tapes on the Bendix Ground Data System to locate truth sites on moving window TV.

2. Mapping data viewed on display into 'gray-scaled' computer printout.

3. Editing exact truth site(s) by use of scan line count and resolution element number.

4. Computing mean signal and standard deviation on edited truth site(s) areas.

5. Transforming mean signal in digital bits into radiance units (mW/cm^2-sr).

6. Using RPMI derived values of Global Irradiance H, Beam Transmittance τ, and Path Radiance L_{ATM} to transform ERTS radiance in each band to reflectance.

The accuracy of this process will be determined when we have RPMI measurement concurrent with ERTS overflight of truth sites.

3.0 NEW TECHNOLOGY

A new technology report (please see Attachment-1) describing the RPMIs was submitted in January in compliance with our contract requirements.

4.0 PROGRAM FOR NEXT REPORTING INTERVAL

We plan to measure solar and atmospheric parameters with RPMI for every suitable (clouds < 60%) ERTS overpass of the test site. We will also continue our studies to determine the capability of other techniques, (such as radiation transfer models, transfer calibration, use of spacecraft data alone) to provide the needed solar and atmospheric parameters. As part of this task I plan to request assistance from Dr. Robert S. Fraser of GSFC to assist me, by providing computer runs utilizing his atmospheric models programmed on the GSFC computer.

Field operations are to be conducted to support the NASA C-130 aircraft during the late March ERTS overflight of our test site.

The development of computer software and techniques to transform the RPMI ground measurements and ERTS CCT data to reflectance units will be continued. Although we have successfully gone through the steps some were taken with the aid of a 'slide rule'. Our plans are to automate all data handling and processing within the next reporting period.

One or two suitable ERTS overflights of our test site are expected within the next reporting interval. The CCTs from these overflights will be processed to obtain reflectance units utilizing the ground derived RPMI solar and atmospheric parameters. The accuracy and capability of this procedure will be determined by comparing the reflectance computed from the ERTS tapes with that measured/determined from RPMI spot sampling and the C-130 aircraft 24-channel scanner data.

5.0 CONCLUSIONS

The ERTS-1 experiment is determining the procedures and techniques for best using RPMI to obtain the needed solar and atmospheric parameters. The performance and cost of the RPMI procedure will then be used as a basis to compare alternative techniques for obtaining the atmospheric parameters needed to transform ERTS radiance into absolute target reflectance. Preliminary results indicate that RPMI provides a straightforward procedure that can be employed by any PI to obtain the radiometric calibration of ERTS data, thus making accurate, unambiguous interpretation of his data possible.

Although our field measurement programs have just started, we have established that solar and atmosphere parameters, degrade the radiometric fidelity of ERTS data by large amounts. The beam transmittance τ has been determined to vary more than 6.0% within a single band on a clear day. Path radiance L_{ATM} was found to account for 50% or more of the radiance signal received by ERTS when viewing water and some land masses. This has also been confirmed by computations performed by Dr. R. S. Fraser at GSFC. Global irradiance H causes the spacecraft radiance to vary up to several hundred percent depending upon spacecraft location, time, and local meteorological conditions. Under the assumption of clear sky conditions, computational techniques will provide a fair estimate (within 20 to 30%) of this parameter. The RPMI also provides the ERTS PI with a direct, absolute measurement of this global irradiance in each ERTS MSS band.

6.0 RECOMMENDATIONS

It is recommended that NASA consider a program that would address the basic question, "what is the value of atmospheric corrections."

To answer this question one approach might be to select and support a group of ERTS PIs having experiments that represent a broad range of ERTS data applications, i.e., Agriculture - Crop and Soil Survey, Environmental - air and water pollution, etc., with a radiometric calibration system. This system might be composed of RPMIs or equivalent instruments that would permit the PIs to correct their data for atmospheric effects. An alternative would be to provide to the PIs both corrected and uncorrected data. The PIs would then interpret his ERTS data with and without the atmospheric corrections. A dollar estimate of benefits contributal to correction would be determined.

Cost of corrections would be derived for each PI based on level and type of support provided. The ratio of application benefit to calibration support cost would provide immediately the desired value of the atmospheric corrections for each ERTS data application.

ATTACHMENT I

[redacted]

NEW TECHNOLOGY REPORT

Radiant Power Measuring Instrument (RPMI)

BSR 3498

8 January 1973

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FOREWORD

The Radiant Power Measuring Instrument (RPMI) reported here was developed to support an 'Investigation of Techniques for Correcting ERTS Data for Solar and Atmosphere Effects', Bendix ERTS data user Contract NAS 5-21863 (MMC #655). The RPMI is used for ERTS ground truth.

1. Title: Radiant Power Measuring Instrument (RPMI)

2. Brief Description: The Radiant Power Measuring Instrument (RPMI) provides an ERTS investigator with a capability of obtaining radiometric measurements needed to determine solar and atmospheric parameters that affect the ERTS radiance measurements. With these parameters, ERTS data can be transformed into absolute target reflectance signatures, making accurate unambiguous interpretations possible.

3. Detailed Description: The RPMI is a rugged, hand-carried instrument accurately calibrated to measure both downwelling and reflected radiance within each ERTS multispectral scanner (MSS) band. A foldover handle permits a quick change from wide angle global or sky irradiance measurements to narrow angle radiance measurements from sky and ground targets. These measurements yield ground truth site reflectance and permit calculation of additional parameters such as beam transmittance between spacecraft and ground, and path radiance (path reflectance).

Summary of Characteristics

- Spectral Bands: All measurements made in ERTS MSS bands (0.5 to 0.6 micron (μ); 0.6 to 0.7μ; 0.7 to 0.8μ; and 0.8 to 1.1μ). Bands formed by bandpass filter in switched turret followed by silicon detector.

- Field of View: Two modes

  1. 2π steradian field of view through removable diffuser.
  2. Handle permits 6.0° circular field of view for sky and earth measurements.

- Sensitivity (Measurement Ranges):

  10 range scales permit irradiance measurements from 0.01 to 300.0 watts/meter^2 and radiance measurements from 0.01 to 300 watts/(meter^2 · steradian).

- Calibration Accuracy:

  1. An absolute accuracy of ±5% is maintained over the field operating ranges for a period of over 1 year.
  2. Relative (band to band) accuracy is ± 2.0%.
  3. Repeatability ± 0.5%.

- Frequency Response:

  0 to 1.0 Hz on meter.
  0 to 20 Hz at BNC output.

- Controls: Irradiance/Radiance, Range (10 positions), Band Select (6 positions include the 4 ERTS MSS bands, and a closed and an open position), Meter Zero, Battery Test, and ON/OFF Switch.

- Meter: 3 1/2-inch taut band 1.0% hand calibrated, mirrored scale; scaled 0 to 1.0 and 0 to 3.0 with 50 and 60 divisions, respectively.

- Power Source: 9.0-volt batteries; battery life while operating — 50 to 100 hours.

- Environmental Specifications:

  1. Sealed against dust and humidity to 100%.
  2. Shock and vibration expected in field and aircraft environments.
  3. Storage -55°C to +80°C.
  4. Operational -20°C to +70°C.

- Size: 4 x 7 x 8 in. (10 x 18 x 20 cm).

- Weight: 5.8 pounds (2.6 kg) with batteries.

Measurement Modes

Global Irradiance (H) - 2π steradian field of view for measuring down-welling (incident) radiation in bands identical to ERTS MSS.

Sky Irradiance (H_{SKY}) - Global Irradiance minus direct sun component, in every ERTS MSS band. Angle from zenith to sun is also measured in this mode.

Radiance from Narrow Solid Angles of Sky - Handle serving as field stop permits direct measurements through a 6.0° circular field of view. This mode is also used to measure direct beam solar irradiance.

Reflected Radiation - Used with small calibration panels, cards, to obtain direct measurement of truth site reflectance. Same field of view as above.

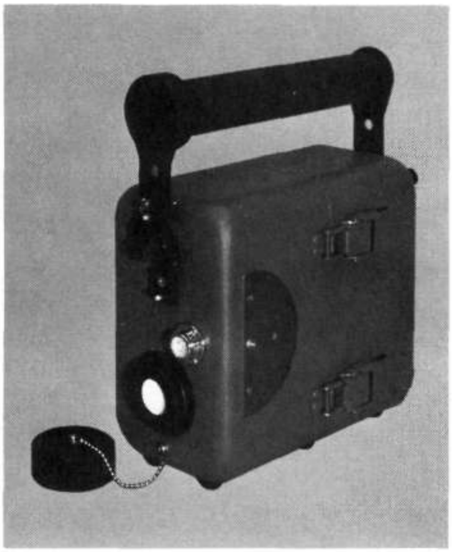
Packaging (See pictures on following page)

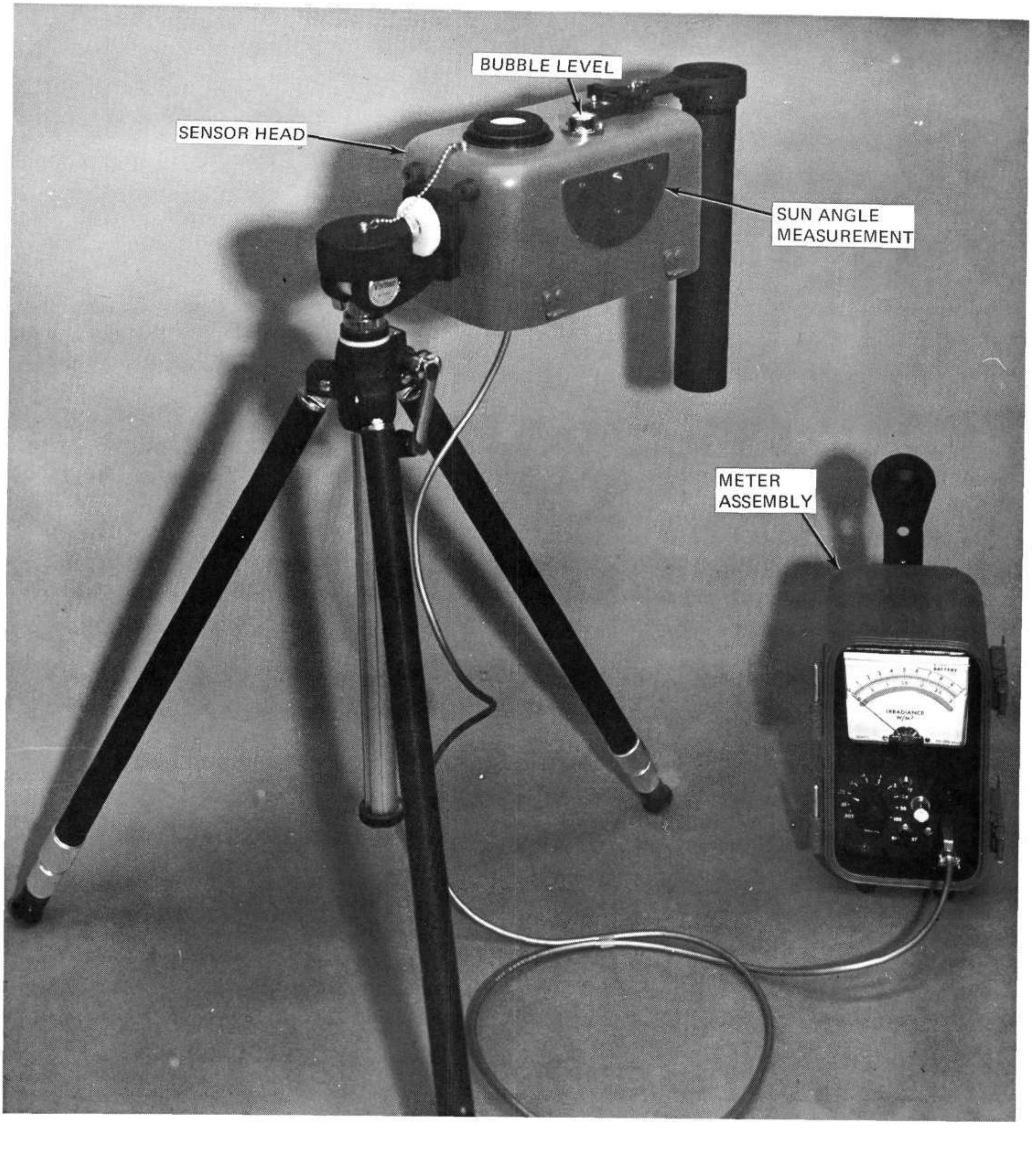
- Handle joins sensor head and meter assembly to form compact unit.
- Sensor head, containing filter wheel and silicon detector, is separated from meter assembly by 6 ft of shielded cable. Sensor head is threaded with standard tripod mounting (1/4-20 tapped hole) to facilitate pointing at sky and ground.
- Bubble level and sun angle measuring device are integral parts of sensor head.
- Foldover handle attached to sensor head permits immediate change from the wide 2π steradian field of view to a narrow one.
- Separate meter assembly facilitates accurate meter reading and permits remote monitoring.

Options

- Filter to match ERTS RBV bands, EREP experiments, etc.
- Circular field of view from 1.0 to 6.0°.

ERTS - Radiant Power Measuring Instrument




BUBBLE LEVEL
SENSOR HEAD
SUN ANGLE
MEASUREMENT
METER
ASSEMBLY
IRRADIANCE
W/M²
BATTERY

[redacted]

4. Applications and Benefits: Measurements made by this instrument permit ERTS MSS data to be transformed into absolute target reflectance signatures, making accurate unambiguous interpretations possible.

   1) Standardization. The measurement and recording of atmospheric parameters with this instrument or ones of equivalent performance are essential if the observations and reports of large numbers of PIs are to be correlated and compared by NASA and other PIs in a meaningful way.

   2) Manual Image Interpretation. Using RPMIs to measure reflectance of test sites directly and/or measuring atmospheric parameters and transforming ERTS data to reflectance units would improve interpretation of ERTS imagery. This instrument will permit the PIs who have knowledge of and have compiled catalogs of spectral reflectance of targets pertinent to their studies to extend the use of this information to ERTS imagery.

   3) Recognization Techniques. RPMI measurements would be used to remove spectral variations due to atmospheric effects from data prior to processing. The benefits in this case includes reduced number of training sites needed and the frequency sites need to be selected to achieve a given level of classification performance by computer procedures.

5. Possible Extensions: The instrument could be modified by changing filters and be used for providing ground truth for ERTS RBV, EREP experiments, etc.

6. Degree of Development: Five instruments were completed during the 1 October through 1 December time period.

7. Technological Significance: In relationship to instruments now being used by most PIs this is a major improvement.

[redacted]

8. Innovator: Robert H. Rogers

9. Publication: The instrument was reported as 'significant results' in Bi-Monthly Progress report for period 1 October to 1 December 1972, for ERTS-Atmospheric Experiment, MMC #655.

[redacted] [redacted]

A TECHNIQUE FOR CORRECTING ERTS DATA FOR SOLAR AND ATMOSPHERIC EFFECTS*

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ABSTRACT

A technique is described by which an ERTS investigator can obtain absolute target reflectances by correcting spacecraft radiance measurements for variable target irradiance, atmospheric attenuation, and atmospheric backscatter. A simple measuring instrument and the necessary atmospheric measurements are discussed. Examples are given which demonstrate the nature and magnitude of the atmospheric corrections.

1. NEED

Target reflectance data are required for unambiguous interpretation of ERTS data. The capability to measure and record atmospheric parameters, and to use these parameters to transform ERTS data to absolute target reflectance signatures, is essential if the observations and reports of large numbers of PIs are to be correlated and compared by NASA and other PIs in a meaningful way. Transforming ERTS data to reflectance units also permit PIs who have knowledge of, and have compiled catalogs of, spectral reflectance of targets pertinent to their studies to extend the use of this information to ERTS imagery. Suppressing spectral variations due to atmosphere also improves computer interpretation techniques by permitting a reduction in the number of training sites needed to achieve a given level of classification performance. In summary, target reflectance data are required by all—man and machine—to maximize the usefulness of ERTS data.

2. PROBLEM

The desired reflectance information is difficult to obtain directly from the ERTS sensor radiance measurements, because these measurements are a function of unknown solar and atmospheric parameters caused by the intervening atmosphere, and these parameters vary significantly. The radiance L, sensed by the spacecraft sensor from a given target, depends not only upon the reflectance, ρ, of the target, but also upon the target irradiance, H, and upon the spectral absorption and scattering

*The results reported were accomplished during the period from August 1972 through February 1973 under NASA Contract No. NAS 5-21863

of the atmosphere between the target and the spacecraft. This atmosphere attenuates the radiance reflected from the target to the spacecraft and adds to the foreground radiance by backscatter of sunlight from the atmosphere, L_{ATM}. The composite radiance, L, recorded within an ERTS band for a spacecraft looking vertically is therefore related to the desired target reflectance ρ and to the solar and atmospheric parameters, H, τ, L_{ATM}, by:

$$L = \frac{\rho}{\pi} H \tau + L_{ATM} \tag{2.1}$$

where τ is the beam transmittance for one air mass. The irradiance, H, falling on the target can be expressed as:

$$H = H_o \tau^m \cos \theta + H_{sky} \tag{2.2}$$

where H_o is the solar irradiance outside the atmosphere, m is the atmospheric air mass in terms of the air mass of the zenith, θ is the solar zenith angle, and H_{sky} is the sky irradiance. L_{ATM} will also have a dependence on θ.

It has been confirmed under ERTS-1 investigation (PR303) that even under the best possible atmospheric conditions, this radiance, L, signal will vary up to 300% even when identical test sites are viewed either repetitively or along a single orbit path. This variation in radiance is due to the contributions and variation of the unknown solar and atmospheric parameters (H, τ, L_{atm}). Thus, the Earth Resources PI who is only interested in his target characteristics, ρ, as a function of wavelength, must also have an independent knowledge of the solar and atmospheric parameters in order to uniquely determine his target reflectance. Without the knowledge of these parameters, the investigator can only interpret his ERTS data based on target spatial features and relative spectral measurements.

3. ERTS-1 ATMOSPHERIC EXPERIMENT PR303

In response to the need for absolute target reflectance signatures, the ERTS-1 Experiment PR303 is evaluating the capabilities of a wide range of candidate techniques for determining and removing solar and atmospheric parameters and effects from ERTS data. Techniques being evaluated include: (1) transferring known ground reflectance to spacecraft measurements, (2) use of the ground-based Radiant Power

Measuring Instrument (RPMI) to measure directly the needed solar and atmospheric parameters, (3) use of spacecraft data alone (no auxiliary inputs), and (4) radiation transfer models employing inputs such as surface pressure, ground visibility, temperature, relative humidity, etc.

This paper describes the results achieved to date in development of the ERTS radiometric calibration techniques employing the RPMI. Section 3 describes the instrument, and in Section 4, the procedures for deploying RPMI to obtain the required solar and atmospheric parameter (H, τ, L_{ATM}) are discussed. In Section 5, the results of using these parameters to transform ERTS radiance into the desired target reflectance is considered.

4. RADIANT POWER MEASURING INSTRUMENT (RPMI)

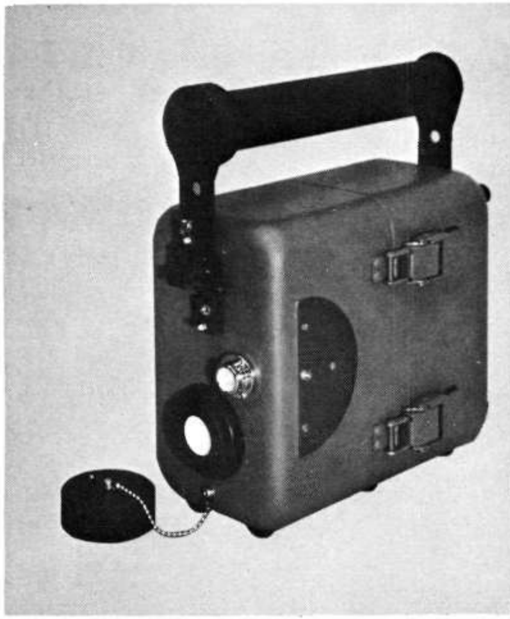
The RPMI, shown in Figure 1, provides an ERTS investigator with the capability of obtaining radiometric measurements needed to determine solar and atmospheric parameters that affect the ERTS radiance measurements. With these parameters, ERTS data are transformed into absolute target reflectance signatures, making accurate, unambiguous interpretations possible.

The RPMI is a rugged, hand-carried instrument accurately calibrated to measure both downwelling and reflected radiance within each ERTS multispectral scanner (MSS) band. A foldover handle permits a quick change from wide-angle global or sky irradiance measurements to narrow-angle radiance measurements from sky and ground targets. These measurements yield ground truth site reflectance and permit calculation of additional parameters such as beam transmittance between spacecraft and ground, and path radiance (path reflectance).

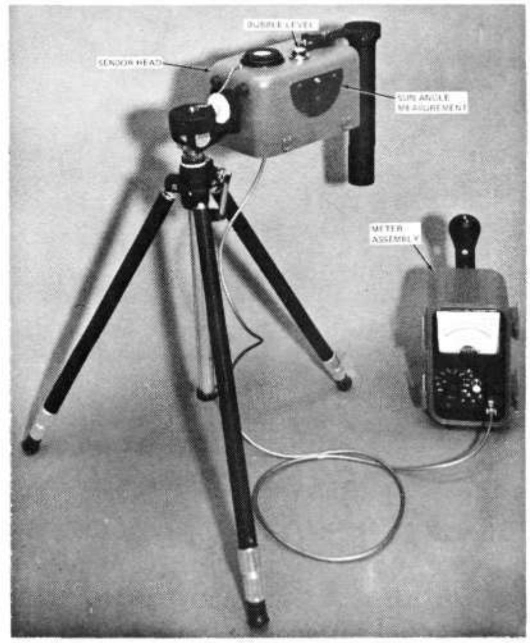
Summary of Characteristics

- Spectral Bands - All measurements made in ERTS MSS bands (0.5 to 0.6 micron (μ); 0.6 to 0.7 μ; 0.7 to 0.8 μ; and 0.8 to 1.1 μ). Bands formed by bandpass filter in switched turret followed by silicon detector.

- Field of View - Two modes: (1) 2π steradian field of view through diffuser; (2) handle permits 6.0° circular field of view for sky and earth measurements.

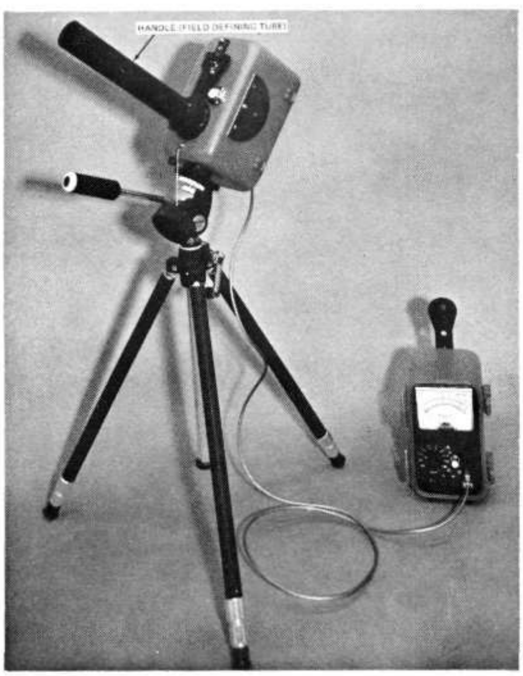


RMI Assembled

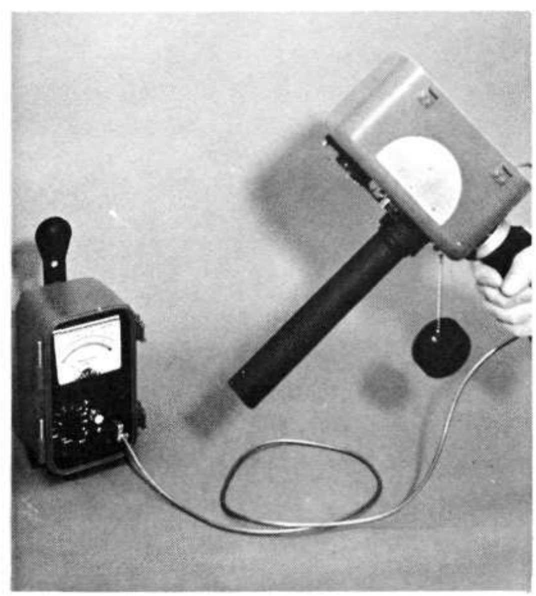


Global Irradiance (H) – 2π steradian field of view for measuring downwelling (incident) radiation ERTS MSS bands. Bubble level aids this measurement.

Sky Irradiance (H_{SKY}) – Block sun to measure global irradiance minus direct sun component, in every ERTS MSS band. Angle from zenith to sun is also measured in this mode by reading sun's shadow cast on sun dial.



Radiance from Narrow Solid Angles of Sky – Handle serving as field stop permits direct measurements through a 6.0° circular field of view. This mode is also used to measure direct beam irradiance.



Reflected Radiation – Used with small calibration panels, cards, to obtain direct measurement of truth site reflectance. Reflectance also immediately derived from ratio of reflected radiance and global irradiance.

Figure 1 Radiant Power Measuring Instrument

- Sensitivity (measurement ranges) - 12 range scales permit irradiance measurements from 0.001 to 300 watts/meter^2 and radiance measurements from 0.1 to 3 x 10^4 watts/(meter^2 · steradian).

- Calibration Accuracy - (1) An absolute accuracy of ±5.0% is maintained over the field operating ranges for a period of over 1 year; (2) Relative (band to band) accuracy is ±2.0%; (3) Repeatability ±0.5%.

- Frequency Response - (1) 0 to 1.0 Hz on meter; (2) 0 to 20 Hz at BNC output.

- Controls - Irradiance/Radiance, Range (12 positions), Band Select (6 positions include the 4 ERTS MSS bands, and a closed and an open position), Meter Zero, Battery Test, and ON/OFF Switch.

- Meter - 3 1/2-inch taut band 1.0% hand-calibrated, mirrored scale; scaled 0 to 1.0 and 0 to 3.0 with 50 and 60 divisions, respectively.

- Power Source - 9.0-volt batteries; battery life while operating — 50 to 100 hours.

- Environmental Specifications - (1) Sealed against dust and humidity to 100%; (2) Shock and vibration expected in field and aircraft environments; (3) Storage -55°C to +80°C; (4) Operational -20°C to +70°C.

- Size - 4 x 7 x 8 in. (10 x 18 x 20 cm).

- Weight - 5.8 pounds (2.6 kg) with batteries.

4.1 Measurement of Atmospheric Parameters

As Figure 1 shows, the RPMI is deployed in concert with ERTS overflights to obtain the direct measurements, within the four ERTS MSS bands, of: (1) global irradiance, H, (2) sky irradiance H_{sky} (i.e., by shadowing sun, and reading global minus direct beam-solar), (3) radiance from a narrow solid angle of sky L_{meas} (ϕ), and (4) direct beam-solar irradiance H_{sun} (m). From these measurements additional solar and atmospheric parameters such as beam transmittance τ and path radiance L_{ATM} are determined. With these parameters the target reflectance is computed by:

$$\rho = \frac{\pi}{H\tau} (L - L_{ATM}) \qquad (4.1)$$

for each ERTS band, in terms of spacecraft radiance measurements, L, and the solar and atmospheric parameters H, τ, and L_{ATM}. The remainder of this section discusses techniques being evaluated to determine these parameters and employ them to transform the ERTS data into the desired absolute target reflectance characteristics.

Global Irradiance H - The radiation falling on the target is measured directly in each ERTS MSS band, as shown in Figure 1. Since this instrument employs a roughened flashed opal disc for a diffuser to obtain this 2π steradian measurement, and diffusers of any type introduce some error as a function of sun angle, additional accuracy in H may be obtained by measuring direct beam solar irradiance H_{sun} (m), sun zenith angle θ, and sky irradiance H_{sky}. These parameters are then simply combined by:

$$H = H_{sun}(m)\cos\theta + H_{sky} \tag{4.2}$$

H_{sun} is a direct meter reading when RPMI is pointed at the sun as in Figure 1. Sky irradiance is also a direct meter reading when the instrument is mounted horizontally, as shown in Figure 1 and the direct-beam sun component is blocked (shadowed out). Sun angle measured from the zenith is also read directly from the sun dial in this mode. Additional accuracy may be obtained if desired by computing sun angle.

Beam Transmittance, τ - One method for determining the beam transmittance τ is to use the RPMI to obtain an "extinction" curve. This technique, widely used by astronomers, follows:

- Measure the direct beam solar irradiation H_{sun} (m) for a range of solar zenith angles. This is a direct meter reading when the RPMI is pointing at the sun as in Figure 1.

- For each measurement, calculate air mass $m = \sec\theta$.

  For sun angles greater than 70°, a more accurate value of m is given by the equation: $m = \sec\theta - 0.0018167(\sec\theta - 1) - 0.002875(\sec\theta - 1)^2 - 0.0008083(\sec\theta - 1)^3$, the sun zenith angle θ being read directly from the sun dial or calculated.

- Plot log H_{sun} (m) against m and extrapolate to $m = 0$ to read H_o, as shown in the example of Figure 2.

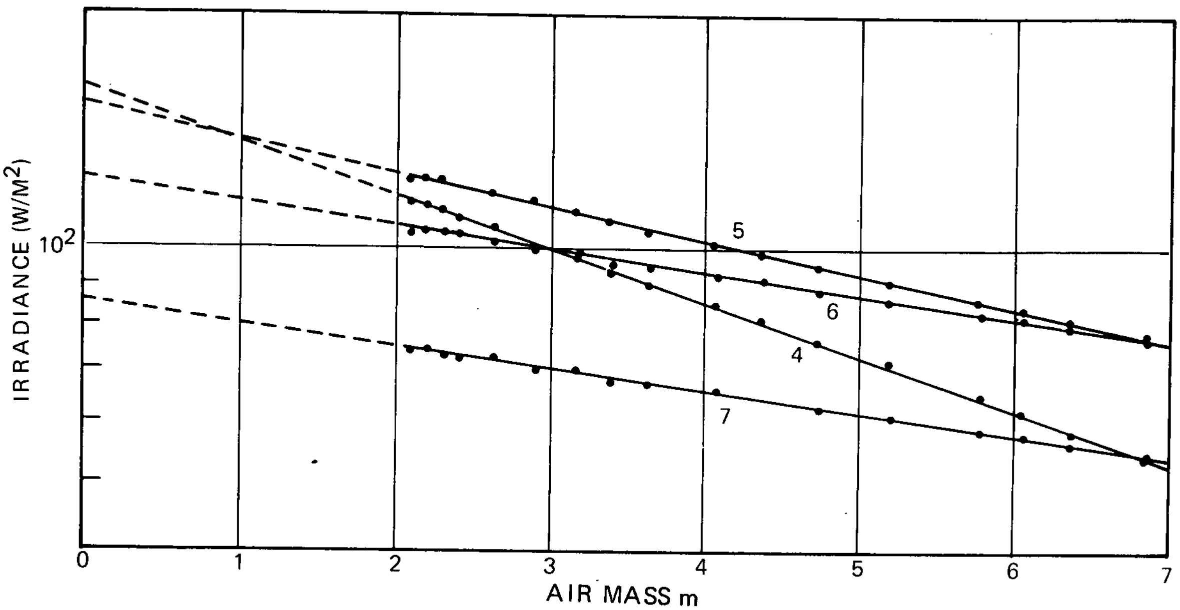


Figure 2 Atmospheric Extinction Curves

The straight lines in Figure 2 indicate excellent, stable atmospheric conditions. The intercept of the lines on the vertical axis give the solar irradiance H_o outside the atmosphere in each of the four MSS bands. The slopes of the lines give the atmospheric attenuation τ, which, as expected, increases with decreasing wavelength. The measured values of H_o can be compared with known values and used as a direct calibration of the instrument. This powerful calibration technique permits recalibration of the RPMI on a clear day at any place in the world without the use of additional equipment or complicated computation procedures.

The parameter τ is determined for each ERTS band in terms of fractional absorption per air mass by obtaining the slope of the curves in Figure 2, which is simply:

$$\tau = \left(\frac{H_{sun}(m_1)}{H_{sun}(m_2)} \right)^{\frac{1}{m_1 - m_2}} \qquad (4.3)$$

where:

$H_{sun}(m_1)$ = direct beam solar irradiance at air mass m_1.
$H_{sun}(m_2)$ = direct beam solar irradiance at another air mass m_2.

The atmosphere properties along the spacecraft-to-target path are assumed to be the same as along the instrument-to-sun path.

A disadvantage of this method is the necessity of making a series of measurements over several hours to obtain a range of sun angles. However, if a single good extinction curve is obtained on a clear day with each instrument, the instruments can be calibrated directly against the sun. Future measurements at a single zenith angle, such as one when ERTS passes over the test site, can then be used to find the atmospheric transmission τ.

In this case, the atmospheric transmission, τ (θ) along the sun-to-instrument path, will be given by:

$$\tau\ (\theta) = \frac{H_{sun}\ (m)}{H_o} \tag{4.4}$$

The sun-target transmittance is used to calculate the target-spacecraft τ (S) transmittance, using:

$$\tau\ (S) = \tau\ (\theta)^{\frac{\cos\theta}{\cos S}} \tag{4.5}$$

where S is the spacecraft angle of observation. For most cases, S $S \simeq o$, so:

$$\tau\ (S) = \tau\ (\theta)^{\cos\theta} \tag{4.6}$$

A series of tests is being performed for ERTS-1 to determine the accuracy of such a single point measurement.

Path Radiance, L_{ATM} - The signal detected by the ERTS will have a minimum value for each band which corresponds to the atmospheric radiance. This radiance is caused by Rayleigh and aerosol scattering. As it cannot be measured directly, it must be derived from ground-based measurements of the backscatter.

The simplest technique is to use RPMI to measure the sky radiance L_{meas} (ϕ) scattered at an angle, ϕ as in Figure 3 such that ϕ is identical to ϕ' the angle through which radiation is scattered to the spacecraft and correct the measurement for the difference in air masses between the

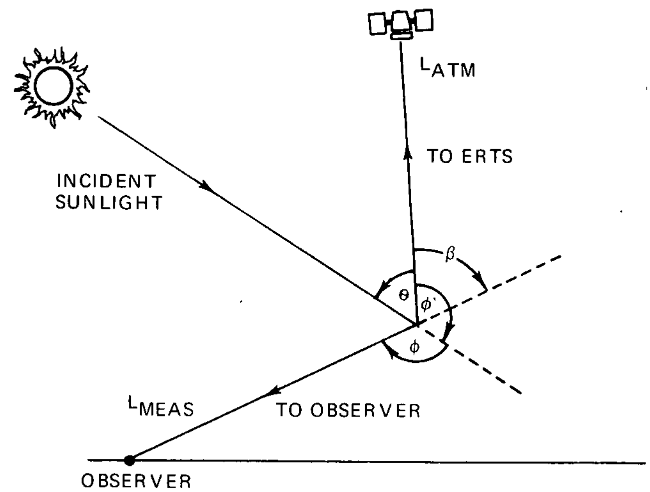


Figure 3 Angular Relationship

direction of observation and the direction of the spacecraft. It is apparent that this RPMI measurement can be made only when the sun zenith angle $\theta > 45°$, which, in some cases, is an unacceptable restriction on the measurements. Atmospheric modeling must be used to extrapolate from the available angles to the desired angle as well as to check the dependence on air mass. A series of measurements is being performed by Bendix to permit an accurate interpolation with a minimum of measurements.

Figure 4A shows RPMI sky radiance measurements as a function of scattering angle ϕ and air mass. Each of the solid lines was obtained by pointing the RPMI at the sun and then sweeping it in azimuth, taking readings at 20° intervals for a particular elevation angle. The broken line was produced by taking readings at different elevation angles from the sun for zero azimuth. The scattering angle, ϕ, is found from:

$$\cos \phi = \sin \theta \sin \beta \cos \alpha + \cos \theta \cos \beta \qquad (4.7)$$

in which θ is the solar zenith angle, β is the zenith angle of the observation, and α is the azimuth measured from the sun. The air masses given in Figure 4A are the values in the direction of the observation. The air mass is continuously variable along the broken curve.

The atmospheric scattering along the line of sight should be proportional to $(1 - \tau^m)$ in which τ is the atmospheric transmission for one air mass

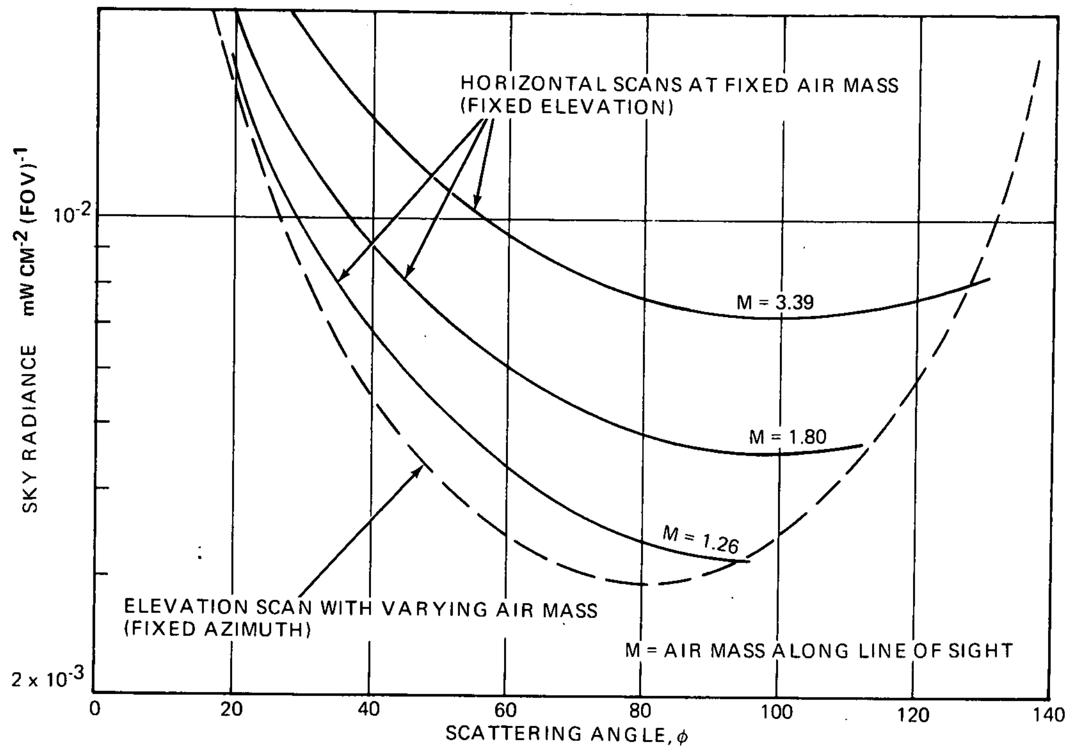


Figure 4A Atmospheric Radiance: Band 4

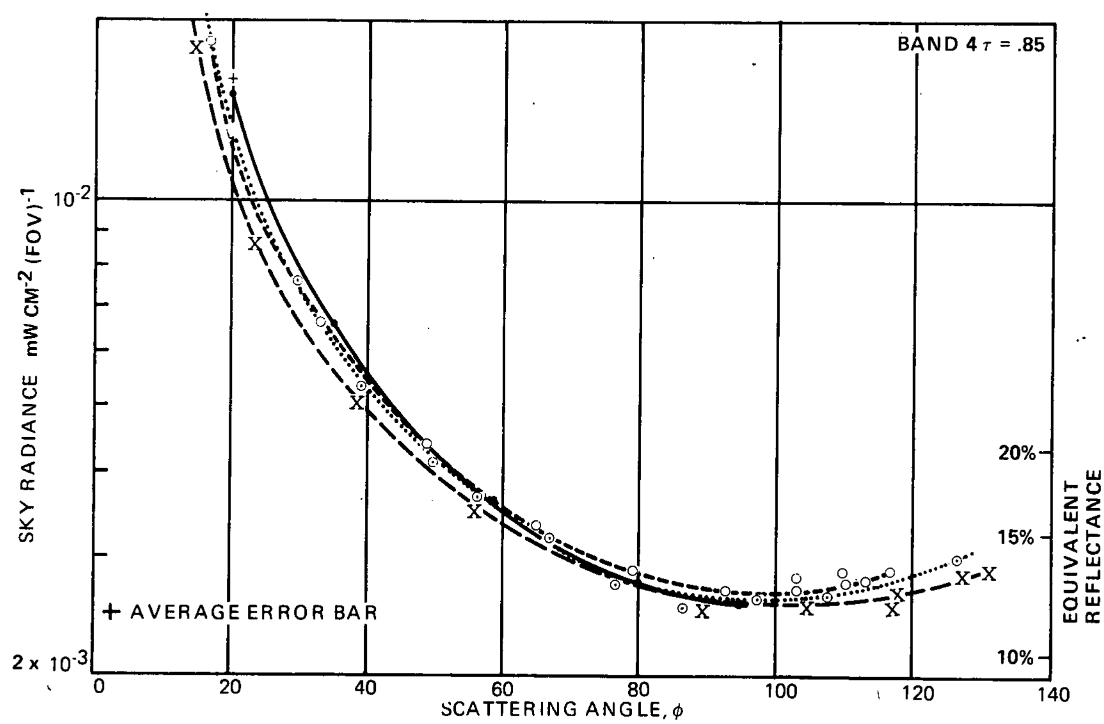


Figure 4B Scattering Data Corrected for Air Mass and τ^m is the transmission of air mass m. Thus, if the RPMI radiance measurement L_{meas} is taken at a scattering angle equal to the scattering angle to the ERTS, the path radiance seen by ERTS should be related by:

$$L_{ATM} \doteq L_{meas} \left[\frac{1 - \tau}{1 - \tau^m}\right] \quad (4.8)$$

assuming the spacecraft is looking vertically through one air mass. This formula has been used by S.Q. Duntley, C.F. Edgerton, and others.

To check the validity of the formula, each of the results in Figure 4A was multiplied by the term in equation 4.8, the value of τ having been determined from an extinction curve. When the curves are replotted, the angular distribution has the form shown in Figure 4B. Considering that the RPMI angular pointing accuracy was only $\pm 1°$ for this test and the atmospheric conditions were unsettled (clearing of a slight haze caused τ to increase from 0.80 to 0.85 in 3-4 hours), the agreement of the curves is excellent. The angular distribution is consistent and the radiance variation at any point is only ±5%, or considerably less if the least accurate curve, the lower one, is given less weight. Thus, for a sun angle of 60° the sky radiance seen by ERTS is given by the value at a scattering angle of 120° (i.e., 180° - θ).

These observations are continuing to determine the repeatability of the curves and the accuracy if measurements at only one or two angles are used to determine L_{ATM}. It may be possible to determine the curve by making a single measurement at an angle of 90° from the sun.

5. EXAMPLE OF ERTS DATA CORRECTION

Since the completion of the RPMIs, local weather conditions have prevented atmospheric observations on the day of an ERTS overpass. Thus, the following comparison of atmospheric data from 12 Feb 1973 with ERTS data from 28 Sep 1972 is only to demonstrate the magnitude of the corrections and is not intended to be an accurate analysis.

Values of ERTS atmospheric path radiance were derived from data taken at Bendix in Ann Arbor, Michigan on 12 Feb 1973. The weather condition — average haze — caused low atmospheric transmission. Using the previously described procedure, the RPMI sky radiance measurements, L_{meas} were corrected to one air mass, and the corrected values in each of the four ERTS MSS bands were plotted as a function of the scattering angle. For a scattering angle of 131° (solar zenith angle 49°) to the ERTS, the values of L_{atm} computed for bands 4 to 7 are listed in Table 1. These have also been converted to bit equivalents based on 7-bit levels for bands 4, 5, and 6, and a 6-bit level for band 7. The table also lists the atmospheric path radiance signal as a percentage of the full scale ERTS channel reading.

Table 1 Atmospheric Radiance Values

Band	L_{ATM} ($mW/cm^2/sr$)	Bit Equivalent	% Full Scale	ERTS Data ($mW/cm^2/sr$) Barton Pond	Bank of River
4	0.274	14	11	0.476	0.508
5	0.118	7.5	5.9	0.242	0.276
6	0.082	6	4.7	0.141	0.402
7	0.1062	1.5	2.4	0.234	1.10

Listed in the last two columns of Table 1 are radiance values taken from ERTS data for 28 Sept 1972. The first is for water and the second is a low-lying area near the Huron River in Ann Arbor. For water, it is noted from the table that over 50% of the signal received by the spacecraft is atmospheric path radiance.

Table 2 summarizes the additional data necessary for the calculations of target reflectances. The values of H_o and τ are derived from the extinction curve as described in Section 4 using data from 12 Feb 1973. The global irradiance H is derived from the previous equation 2.2 using a typical measured value of sky irradiance H_{sky}. Under normal circumstances, the direct beam solar irradiance $H_o\tau^m$ is a fast direct measurement made at the time of the ERTS flyover, but as the atmospheric data and the ERTS results were for different sun angles, equation 2.2 was used to determine the global irradiance H. The results are given in the table. Finally, the data were used to calculate the reflectance of the target using equation 4.1. The results are now absolute values and are free of atmospheric and solar effects. Examples of two different targets, a small lake and a low-lying river bank, are given in Table 2.

Table 2 Calculation of Target Reflectivity

Band	H_o (mW/cm^2)	τ	Global Irradiance (mW/cm^2)	Target Reflectivity	
				Barton Pond (%)	River Bank (%)
4	15.05	0.81	8.41	9.3	10.8
5	13.98	0.865	8.14	5.5	7.5
6	12.00	0.909	7.38	2.8	15
7	8.57	0.913	5.02	0.9	6.8

6. SUMMARY

The ERTS-1 experiment is determining the procedures and techniques for best using RPMI to obtain the needed solar and atmospheric parameters. The performance and cost of this procedure will then be used as a basis to compare other techniques for obtaining the atmospheric parameters needed to transform ERTS radiance into absolute target reflectance. Preliminary results indicate that RPMI will provide a straightforward, low-cost procedure that could be employed by all PIs to obtain the needed radiometric calibration of ERTS data, thus making accurate, unambiguous interpretations possible.

Although our field measurement programs have just started, we have established that solar and atmosphere parameters degrade the radiometric fidelity of ERTS data by large amounts. The beam transmittance τ has been determined to vary more than 6.0% within a single band on a clear day. Path radiance L_{ATM} was found to account for 50% or more of the radiance signal received by ERTS when viewing water and some land masses. This has also been confirmed by computations performed by R. S. Fraser at NASA GSFC. Global irradiance H causes the spacecraft radiance to vary up to several hundred percent depending upon spacecraft location, time, and local meteorological conditions. Under the assumption of clear sky conditions, computational techniques will provide a fair estimate (within 20 to 30%) of global irradiance. The RPMI provides the ERTS PI with a direct, absolute measurement of this parameter in each ERTS MSS band.

It is hoped that the results of this investigation will support NASA in its continuing effort to identify and bring together the most cost-effective grouping of instruments and techniques to achieve radiometric calibration of ERTS data gathered on a world-wide basis.